

Contribution of Soil Moisture Information to Streamflow Prediction in the Snowmelt Season: A Continental-Scale Analysis

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In areas dominated by winter snowcover, the prediction of streamflow during the snowmelt season may benefit from three pieces of information: (i) the accurate prediction of weather variability (precipitation, etc.) leading up to and during the snowmelt season, (ii) estimates of the amount of snow present during the winter season, and (iii) estimates of the amount of soil moisture underlying the snowpack during the winter season. The importance of accurate meteorological predictions and wintertime snow estimates is obvious. The contribution of soil moisture to streamflow prediction is more subtle yet potentially very important. If the soil is dry below the snowpack, a significant fraction of the snowmelt may be lost to streamflow and potential reservoir storage, since it may infiltrate the soil instead for later evaporation. Such evaporative losses are presumably smaller if the soil below the snowpack is wet.

In this paper, we use a state-of-the-art land surface model to quantify the contribution of wintertime snow and soil moisture information – both together and separately – to skill in forecasting springtime streamflow. We find that soil moisture information indeed contributes significantly to streamflow prediction skill.

Our first analysis makes use of a “synthetic truth” dataset of target springtime (March-May, or MAM) streamflows across the continental United States (CONUS). These streamflows are produced by driving the land surface model for multiple decades with an observations-based multi-decadal meteorological forcing data set (Wang et al., in press). The streamflows generated by the land model under this forcing are assumed to be realistic, at least in terms of their inter-annual variability.

Once this “truth” is established, we forecast the streamflows for each year in the multi-decadal period in two different ways: (i) by initializing the land model with the snow and soil moisture fields produced by the offline simulation for January 1 of each year and then driving the model from January through May of each year with climatological meteorological forcing, i.e., under the assumption that we have no knowledge whatsoever of the meteorological forcing during the forecast period; and (ii) by repeating this set of forecasts with the additional limitation of not knowing the soil moisture initial conditions, i.e., by initializing the snow to realistic values but the soil moisture field to its climatological mean for January 1. A comparison of predicted MAM streamflows from the first set of forecasts against the assumed synthetic truth reveals the combined contribution of January 1 snow and soil moisture information to streamflow forecast skill across CONUS. Similarly, the second set of forecasts shows how snow information by itself contributes to skill. The contribution of soil moisture to forecast skill is quantified by subtracting the skill found in the second set of forecasts from that found in the first.

Our analysis shows that January 1 snow and soil moisture information provides considerable skill to MAM streamflow prediction in the Rocky Mountains and around the Great Lakes. Furthermore, we find that soil moisture by itself is a significant contributor to this skill, providing as much as 0.15-0.25 to the r^2 skill scores measured for these regions. In the realm of seasonal forecasting, such skill contributions are indeed very large.

Of course, a comparison against synthetic truth is in some ways unsatisfying. We therefore supplemented the above analysis with a comparison of our streamflow forecasts against MAM streamflows measured at a handful of stream gauges scattered across the western United States, stream gauge measurements that have been naturalized to remove the impact of reservoir operations. While the resulting spatial picture of skill contribution is necessarily much more limited, our comparison against the stream gauge measurements confirms the findings above, with r^2 skill score contributions from soil moisture amounting to 0.2 in many places.

Observations of surface soil moisture should be available soon from two satellite missions: the Soil-Moisture-Ocean-Salinity (SMOS; projected launch in 2009) mission and the Soil-Moisture-Active-Passive (SMAP; projected launch in 2013) mission. Our results highlight a potentially powerful application of such soil moisture retrievals, given the reasonable assumption that soil moistures measured just prior to snowpack formation remain

representative of conditions under the developing snowpack. In particular, our results emphasize the need for a better understanding of (i) soil moisture retrievals in mountainous regions and (ii) the estimation of root zone soil moisture from the space-based surface observations, e.g., through data assimilation.

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